NATIONAL BUREAU OF STANDARDS REPORT

3901

THERMAL CONDUCTIVITIES OF THREE INCONEL ALLOYS AT TEMPERATURES FROM 100 TO 700°C

by

H. E. Robinson
Silas Katz

Report To

The
National Advisory Committee
For Aeronautics
Washington 25, D.C.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

Electricity. Resistance and Reactance Measurements. Electrical Instruments. Magnetic Measurements. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels. Cryogenic Engineering.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Measurements. Infrared Spectroscopy. Nuclear Physics. Radioactivity. X-Ray. Betatron. Nucleonic Instrumentation. Radiological Equipment. Atomic Energy Commission Radiation Instruments Branch.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Control.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering.

Electronics. Engineering Electronics. Electron Tubes. Electronic Computers. Electronic Instrumentation. Process Technology.

Radio Propagation. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Frequency Utilization Research. Tropospheric Propagation Research. High Frequency Standards. Microwave Standards.

●Office of Basic Instrumentation ●Office of Weights and Measures.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT **NBS REPORT**

1003-30-1015 January 19, 1955 3901

THERMAL CONDUCTIVITIES OF THREE INCONEL ALLOYS
AT TEMPERATURES FROM 100 TO 700°C

by

H. R. E Robinson
Silas Katz

Heating and Air Conditioning Section
Building Technology Division

to

National Advisory Committee
For Aeronautics
Washington 25, D.C.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THERMAL CONDUCTIVITIES OF THREE INCONEL ALLOYS AT TEMPERATURES FROM 100 TO 700°C

1. INTRODUCTION

Three Inconel alloys were submitted by the National Advisory Committee for Aeronautics for measurements of their thermal conductivities in the temperature range from 100° to 700°C. Three specimens of each alloy were furnished, these being designated as NX9519 (1,2,3); NX592 (4,5,6); NX656 (7,8,9).

This report presents the results of measurements made on two specimens of each of the three alloys (Specimens 2, 3; 5, 6; 8, 9).

2. DESCRIPTION OF THE ALLOYS AND SPECIMENS

According to information furnished by the International Nickel Company, the compositions of the alloys were as follows:

	NX 9519	NX 592	NX 656
C	.02	.07	.11
Mn	.28	.26	.33
Fe	8.87	7.89	8.17
Si	.17	.19	.21
Cu	.22	.15	.19
Ni	75.99	76.45	75.64
Cr	14.42	14.96	15.32
S	.007	.007	.007

The specimens were cylindrical bars, machined to a length of 37.8 cm and a uniform diameter of 2.42 cm. An axial hole, 1.3 cm in diameter, was drilled to a depth of 5.8 cm in each end of the bar.

According to information obtained from the NACA, the specimens after machining were subjected to heat treatment by being placed in an oven at 1120°C, left there for 9-1/4 minutes, and then removed and allowed to cool in quiescent air.

3. TEST METHOD AND PREPARATION OF SPECIMENS

The general arrangement of the test apparatus with a specimen installed is shown in Figure 1. The test specimen was heated at the bottom by means of the internal electric

heater, and held at a constant temperature at the top by the circulating coolant. The guard cylinder was similarly heated at the bottom and cooled at the top.

Seven thermocouples, spaced about 4 cm apart along the measuring section of the specimen, indicated the temperature at the ends of six 4-cm spans of the bar, thus enabling calculation of six values of the thermal conductivity of the metal, corresponding to six progressively lower mean temperatures, for each temperature regime at which the apparatus was operated.

The internal bar heater was energized with constant voltage direct current, the power input being determined by measurements of the current and potential drop in the heater using standard resistors and a high-precision potentiometer. The guard heater was energized with voltage-stabilized a.c., adjusted to yield a minimal average temperature difference between the bar and the guard as indicated by thermocouples in corresponding longitudinal positions on the bar and guard. Other thermocouples on the bar and guard provided additional temperature data needed to calculate corrections for small heat interchanges between guard and bar. The space between specimen and guard was filled with a free-flowing powder insulation of which the thermal conductivity at various temperatures was known; the guard cylinder was suspended within the outer cylindrical container, and similarly insulated.

Thermocouples on the specimen were made of No. 26 AWG chromel and alumel wires, welded with an oxygen-gas torch to yield small bead-like junctions. These were inserted in 1 mm diameter holes drilled 2 mm deep radially in the side of the specimen, and fastened tightly by punch-pricking the metal around the hole. The thermocouple wires were separately insulated with fine woven glass tubing, and wrapped at least one-half turn around the specimen, in the transverse plane of the junction, before being led away to the top of the apparatus through the powder insulation. The guard thermocouples were similarly installed. All thermocouple emfs were measured against a reference junction at 0°C, using a high-precision potentiometer.

The internal bar heater consisted of a multi-hole ceramic cylinder 1.27 cm in diameter and 5.2 cm long, with nichrome resistance wire threaded longitudinally through the holes. Specimens No. 5 and 8 were tested with a heater of about 30 ohms resistance; all other tests were made with a different heater of about 55 ohms resistance. Low resistance current leads, and fine wire potential leads, were brought out to

the top of the apparatus through the powder insulation.

Results were calculated using average values of data obtained in several readings over a period of three or more hours at a substantially steady-state condition. Temperature conditions were considered satisfactorily steady when no thermocouple on the specimen changed temperature at an average rate greater than 0.3 degree C per hour. Thermocouple readings were converted to degrees Centigrade using data obtained by a calibration of the thermocouple wire.

To calculate the thermal conductivity, observed temperatures of the specimen and guard were plotted versus longitudinal position, and smooth curves were drawn through the points representing the specimen and guard temperatures. Average temperature differences between specimen and guard were determined from these curves, for various parts of the specimen, and used, in conjunction with geometric factors and the known thermal conductivity of the insulation, to calculate heat interchanges between the specimen and the guard. Such corrections to the measured heat input to the specimen heater were calculated for the heat interchange (a) between the lower end of the specimen and the guard, (b) between the specimen and the guard at the heater region up to the first span thermocouple, and (c) between specimen and guard for each of the six thermocouple spans. The average rate of heat flow in the specimen between any two adjacent thermocouples was thus computed and used, together with the measured distance and temperature difference between them, and the cross-sectional area of the specimens, to calculate the average thermal conductivity at the span, corresponding to the average or mean temperature of the span.

The maximum difference for any thermocouple span between the corrected heat flow in the span and the measured electrical input to the heater ranged from -12 to 22 percent of the input in the various tests, averaging 8.7 percent. It is believed that corrections to account for heat interchanges between bar and guard were computed with an uncertainty of less than 15 percent and consequently that the uncertainty in the rates of heat flow used in calculating the thermal conductivities was not more than 3 percent, and in most cases was considerably less.

Measurements were made on each specimen at several different temperature regimes or gradients, each such regime yielding six values of thermal conductivity at six corresponding values of mean temperature. For two of the alloys, the initial test was made on one specimen at a low temperature

and on the other specimen at a moderate or high temperature. In the case of one specimen (No. 8), on which the initial test was made at a high temperature, the specimen was removed from the apparatus, reversed end for end, and retested with the initial test made at a low temperature.

4. TEST RESULTS

The values of thermal conductivity obtained from each of the tests on each specimen were plotted versus their corresponding mean temperatures (Figures 2 through 7). For each set of six values obtained in each test, a straight line was drawn, as determined by the method of least squares. In cases where the initial test on a specimen was made at a low temperature, a dashed line was drawn for that test.

This method of plotting the results indicated that the conductivity -- mean temperature relationships were slightly concave upward. Accordingly, quadratic curves were fitted to the data for each specimen, using the theory of least squares, as shown in Figure 8. One curve sufficed for both specimens of alloy NX 592, and similarly for alloy NX 656, but in the case of alloy NX 9519 the results on the two specimens differed sufficiently to require a curve for each specimen.

The quadratic equations plotted in Figure 8 are given below, together with the standard deviations of the individual conductivity determinations from the corresponding equations. The standard deviation given is a measure both of the errors in individual determinations, and of how well the equation fits the data.

Specimen	Equation	Std.Dev.
NX 9519 - No. 2	$k = 0.1349 + 0.0105x + 0.00090x^2$	0.00301
NX 9519 - No. 3	$k = 0.1356 + 0.0134x + 0.00055x^2$	.00325
NX 592 - Nos. 5 & 6	$k = 0.1342 + 0.0144x + 0.00045x^2$	.00267
NX 656 - Nos. 8 & 9	$k = 0.1345 + 0.0146x + 0.00046x^2$	.00206

where k = thermal conductivity, watt/cm(deg C)

100x = mean temperature, °C. $(0.8 < x < 7.0)$

Values of thermal conductivity (watt/cm deg C) calculated from these equations, and used to plot the curves in Figure 8,

are tabulated below. The fourth digit is presented merely to show differences.

Mean Temp. °C	NX9519 Spec. 2	NX9519 Spec. 3	NX592 Spec. 5,6	NX656 Spec. 8,9
100	0.1464	.1495	.1490	.1496
200	.1596	.1645	.1648	.1656
300	.1746	.1807	.1815	.1825
400	.1914	.1980	.1990	.2004
500	.2100	.2164	.2175	.2191
600	.2304	.2358	.2369	.2388
700	.2526	.2564	.2572	.2594

5. DISCUSSION OF RESULTS

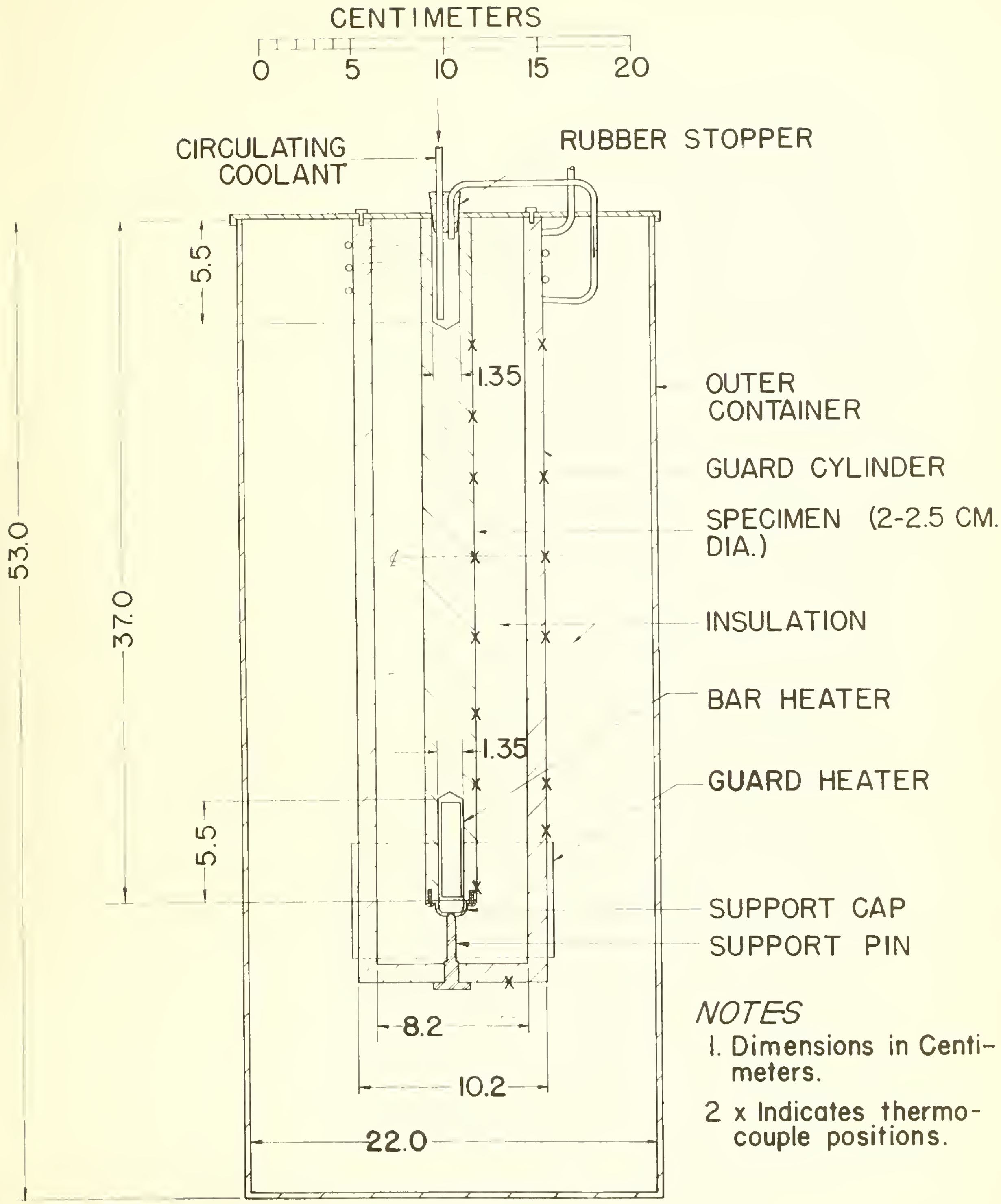
The results, as shown in Figure 8 and by the tabulated values, indicate that the three alloys, as represented by Specimens 3 (NX 9519), 5 and 6 (NX 592) and 8 and 9 (NX 656), had thermal conductivities over the range 100 to 700 C which were the same within one percent. Specimen 2 (NX 9519), however, was about 3 percent lower in conductivity than its comparison specimen (No. 3) of the same alloy, and similarly about 3 percent lower than the specimens of the other two alloys. A retest of Specimen 2 was made, in view of the above, but the results were not significantly different from those first obtained.

Assuming that Specimen 3, rather than Specimen 2, properly represented alloy NX 9519, the differences in conductivity of the three alloys are smaller than the uncertainties in the conductivity results as indicated by the standard deviations from the quadratic curves. If the tabulated conductivity values are taken as virtually comparable, the conductivity of the specimens appeared to increase slightly with carbon content of the alloy, the increase being one percent for an increase of carbon content from 0.02 percent to 0.11 percent according to the manufacturer's composition data. However, in view of the smallness of the differences, the complexity of the alloys, and the variations in their other constituents, the conclusion must be that carbon content, in the range covered, has little effect on the conductivity of the alloy.

For each alloy, the conductivities obtained when the first test of a specimen was made in the low temperature range (see dashed curves of Figures 4 and 7; the same was true of initial tests made on Specimen 2) were a few percent higher than the values at the same mean temperatures obtained in tests of the same specimen conducted at a higher range of temperature,

or in the same low temperature range after tests had been made at higher temperatures. When the first test of a specimen was made in the intermediate or high temperature range (see Figures 3, 5 and 6), all conductivities at the lower mean temperatures were in good agreement. In the case of Specimen 8 (NX 656), tested with the specimen reversed end-for-end (Figure 6A) following the tests shown in Figure 6, the initial test, conducted at low temperatures, yielded results in close agreement with those obtained in later tests conducted at higher temperatures. Similarly, the results obtained initially in a second series of tests of Specimen 2 (NX 9519), shown in Figure 2, were not sensibly different from those obtained in the later tests at higher temperatures, although in the first series of tests of this specimen the initial test, conducted at low temperatures, gave conductivities at low temperatures 4 percent higher than those obtained in later tests in this or the second series.

A heat-treating effect on conductivity was therefore observed consistently for each of the three alloys -- namely, that when heated to only moderate temperatures, and for only several hours, the metal had conductivities a few percent higher than the more stable values that were obtained following longer exposure to similar temperatures, or heating to moderately higher temperatures. The effect was obtained even though the specimens, before submission, had been heat-treated, as described earlier, at temperatures exceeding those reached in these measurements. The effect is probably of little importance practically, but may be of considerable interest as regards the nature of heat treatment effects on Inconel, which could not be thoroughly explored within the scope of these measurements.



APPARATUS FOR MEASURING THE THERMAL CONDUCTIVITY OF METALS

FIGURE 1

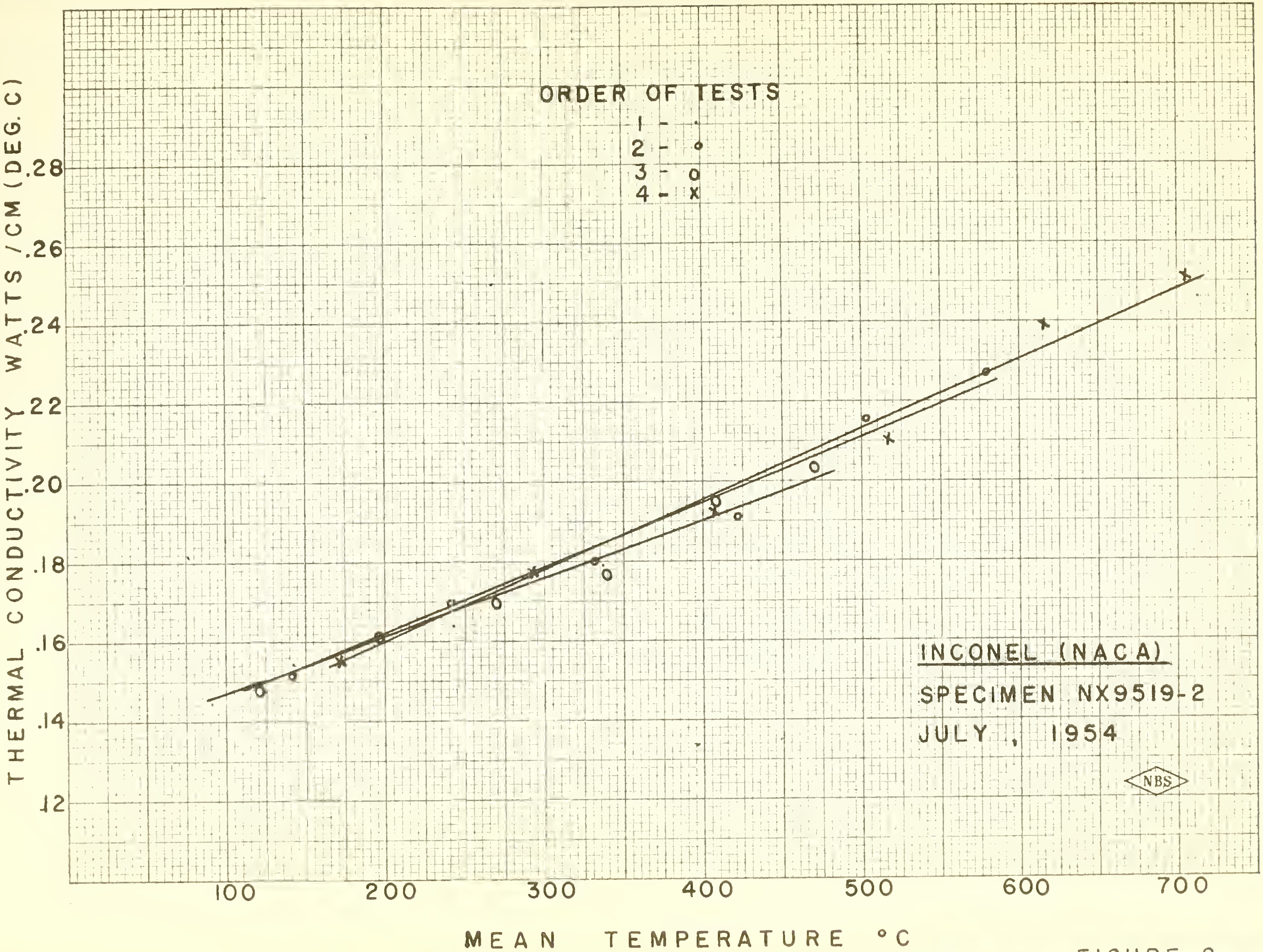

ORDER OF TESTS
1 - ·
2 - ∘
3 - o
4 - x
INCONEL (NACA)
SPECIMEN NX9519-2
JULY, 1954
NBS
THERMAL CONDUCTIVITY WATTS / CM (DEG. C)
.28
.26
.24
.22
.20
.18
.16
.14
.12
100
200
300
400
500
600
700
MEAN TEMPERATURE °C

FIGURE 2

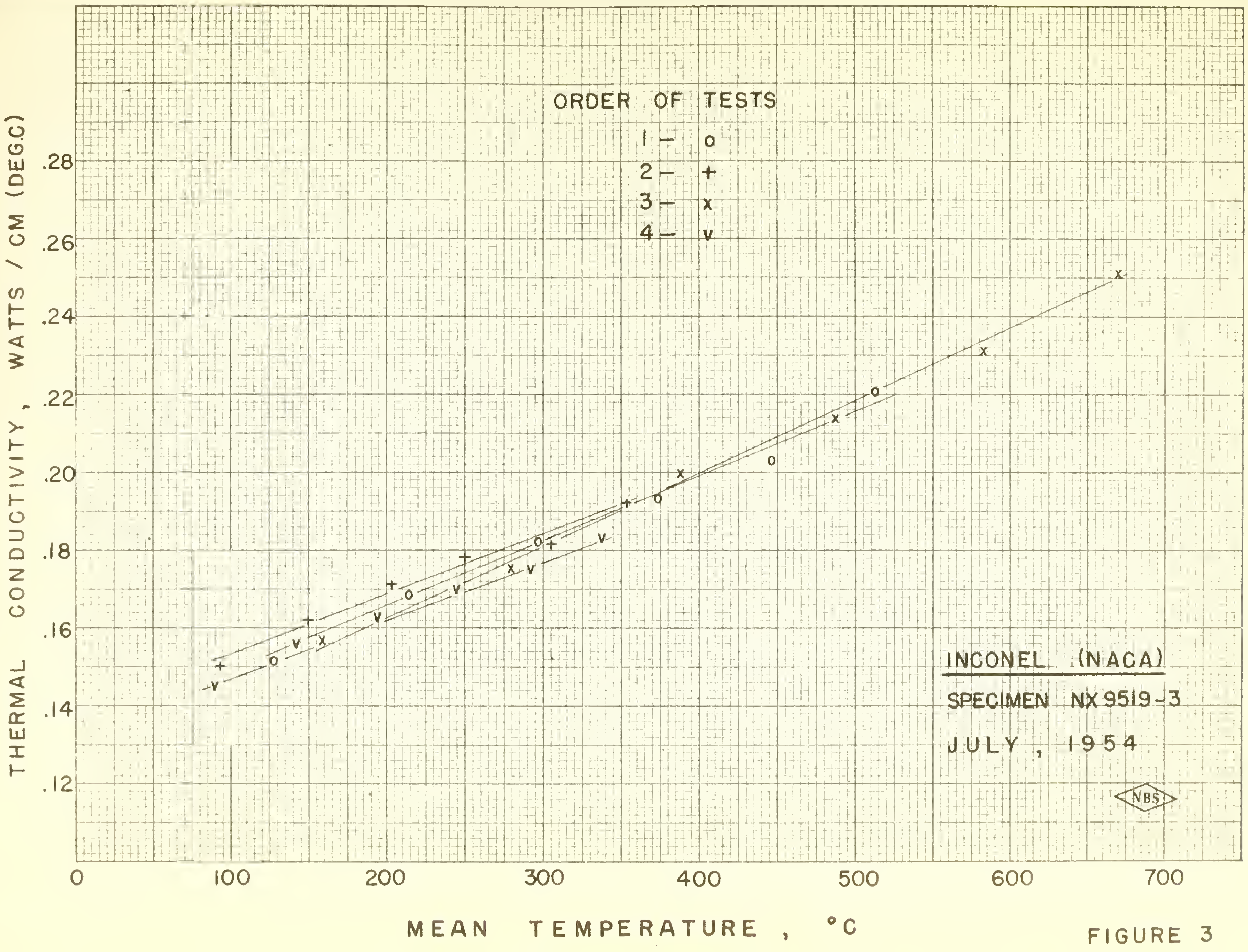

ORDER OF TESTS
1 — o
2 — +
3 — x
4 — v
.28
.26
.24
.22
.20
.18
.16
.14
.12
0
100
200
300
400
500
600
700
THERMAL CONDUCTIVITY, WATTS / CM (DEG.C)
MEAN TEMPERATURE, °C
INCONEL (NACA)
SPECIMEN NX 9519-3
JULY, 1954
NBS

FIGURE 3

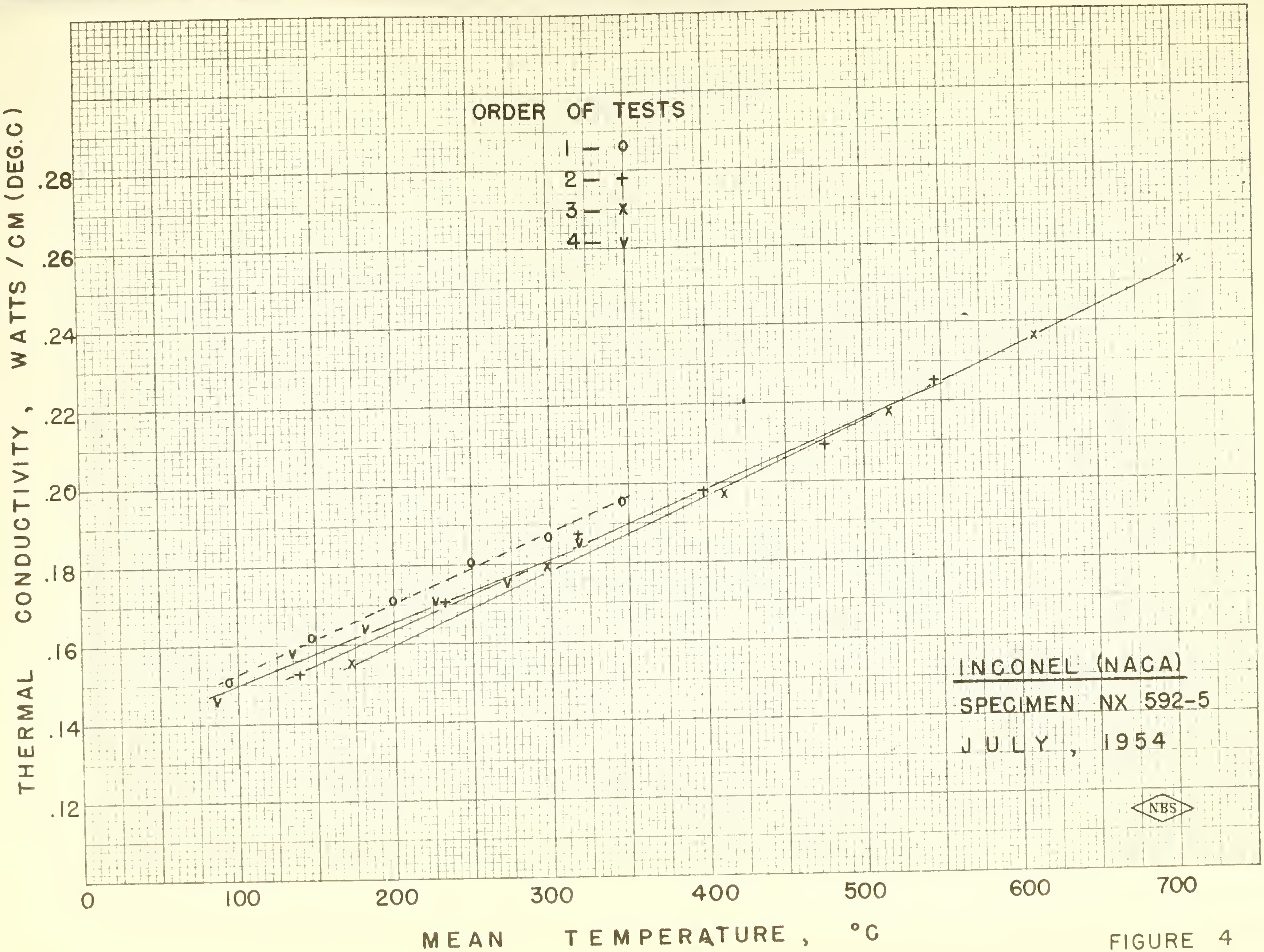
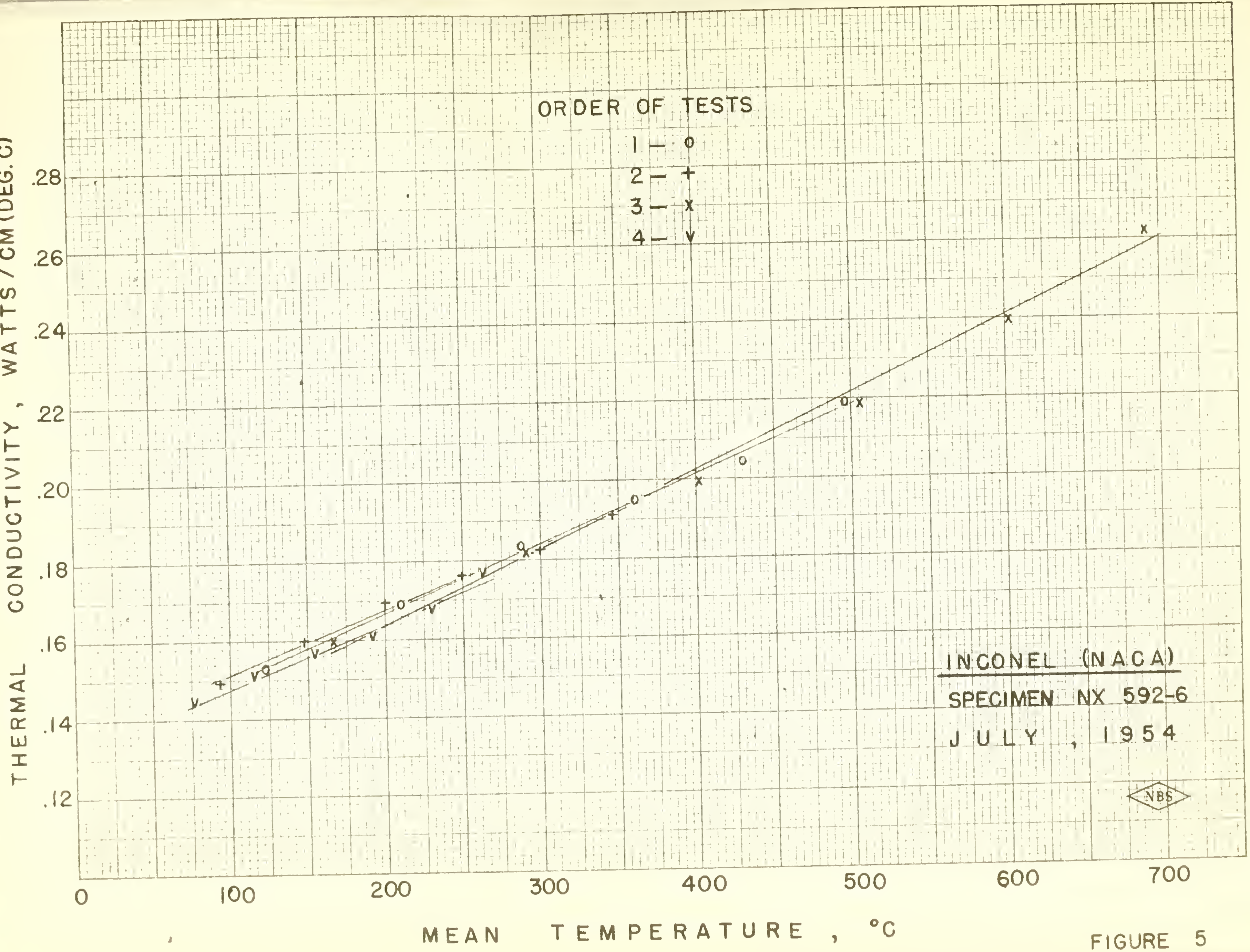

ORDER OF TESTS
1 — o
2 — +
3 — x
4 — v
.28
.26
.24
.22
.20
.18
.16
.14
.12
THERMAL CONDUCTIVITY, WATTS / CM (DEG.C)
0
100
200
300
400
500
600
700
MEAN TEMPERATURE, °C
INCONEL (NACA)
SPECIMEN NX 592-5
JULY, 1954
NBS

FIGURE 4



ORDER OF TESTS
1 — o
2 — +
3 — x
4 — v
INCONEL (NACA)
SPECIMEN NX 592-6
JULY, 1954
NBS
THERMAL CONDUCTIVITY, WATTS / CM (DEG. C)
.28
.26
.24
.22
.20
.18
.16
.14
.12
0
100
200
300
400
500
600
700
MEAN TEMPERATURE, °C

FIGURE 5

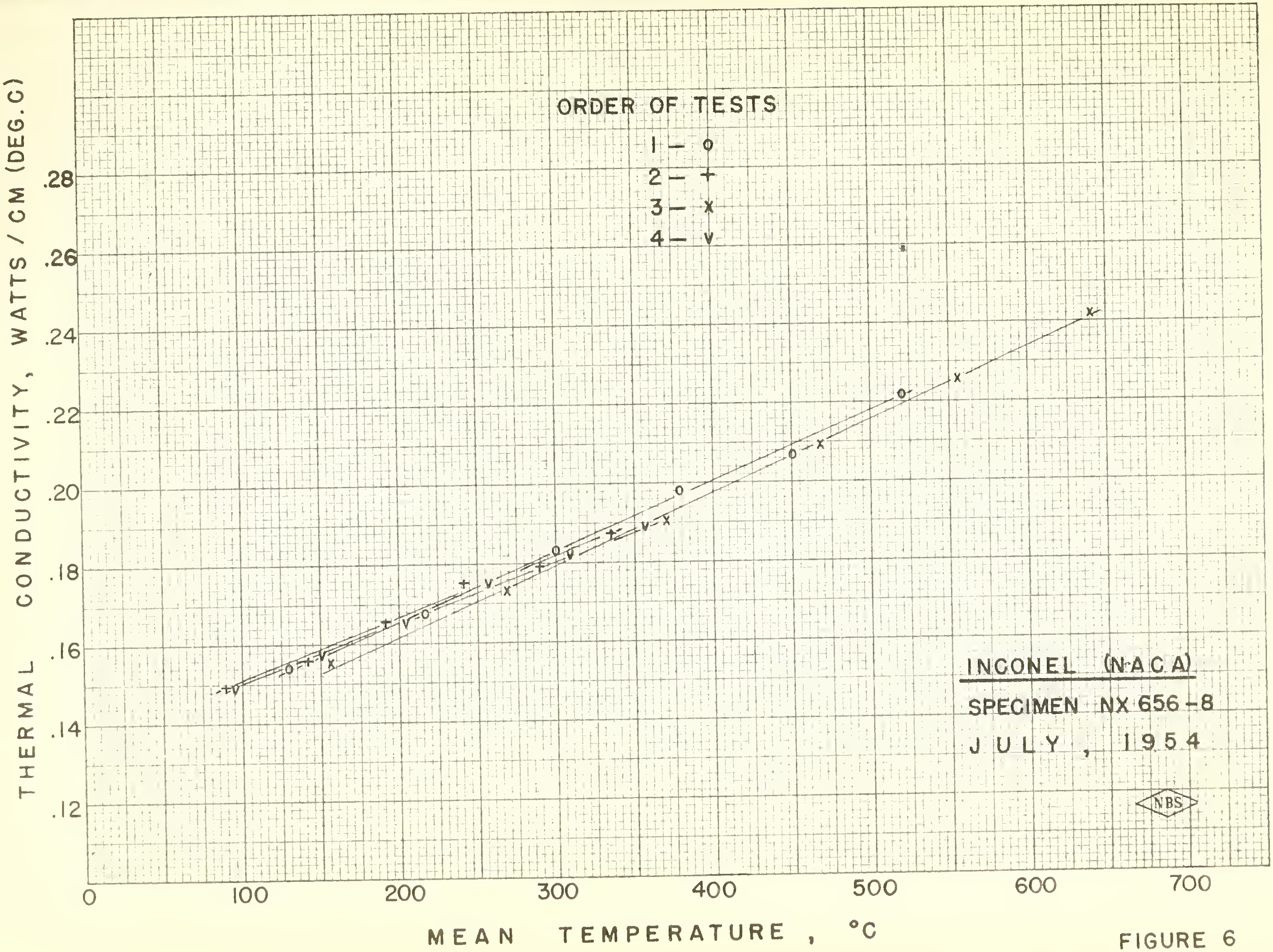

ORDER OF TESTS
1 — o
2 — +
3 — x
4 — v
INCONEL (N.A.C.A)
SPECIMEN NX 656-8
JULY, 1954
NBS
THERMAL CONDUCTIVITY, WATTS / CM (DEG. C)
.28
.26
.24
.22
.20
.18
.16
.14
.12
0
100
200
300
400
500
600
700
MEAN TEMPERATURE, °C

FIGURE 6

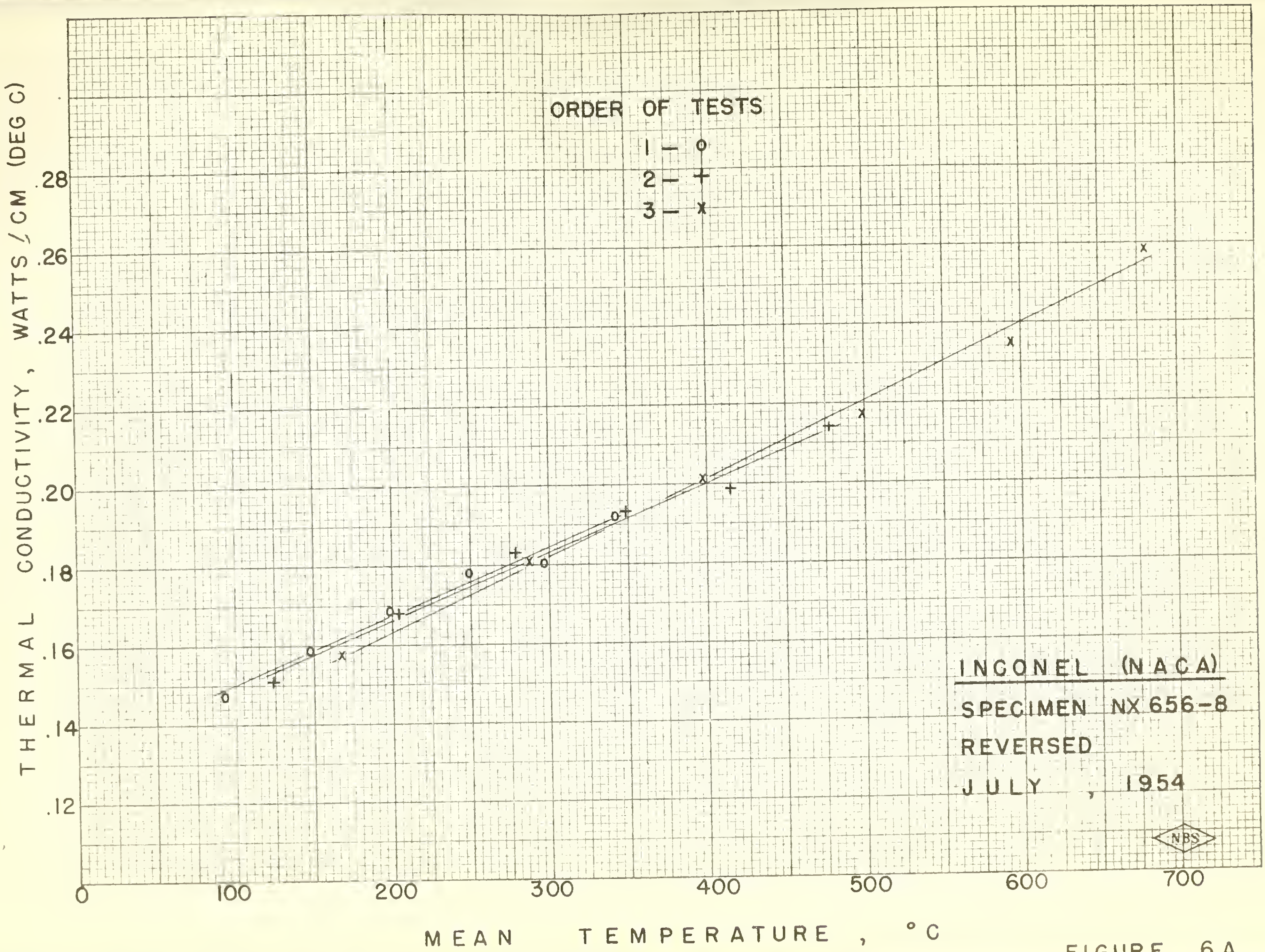
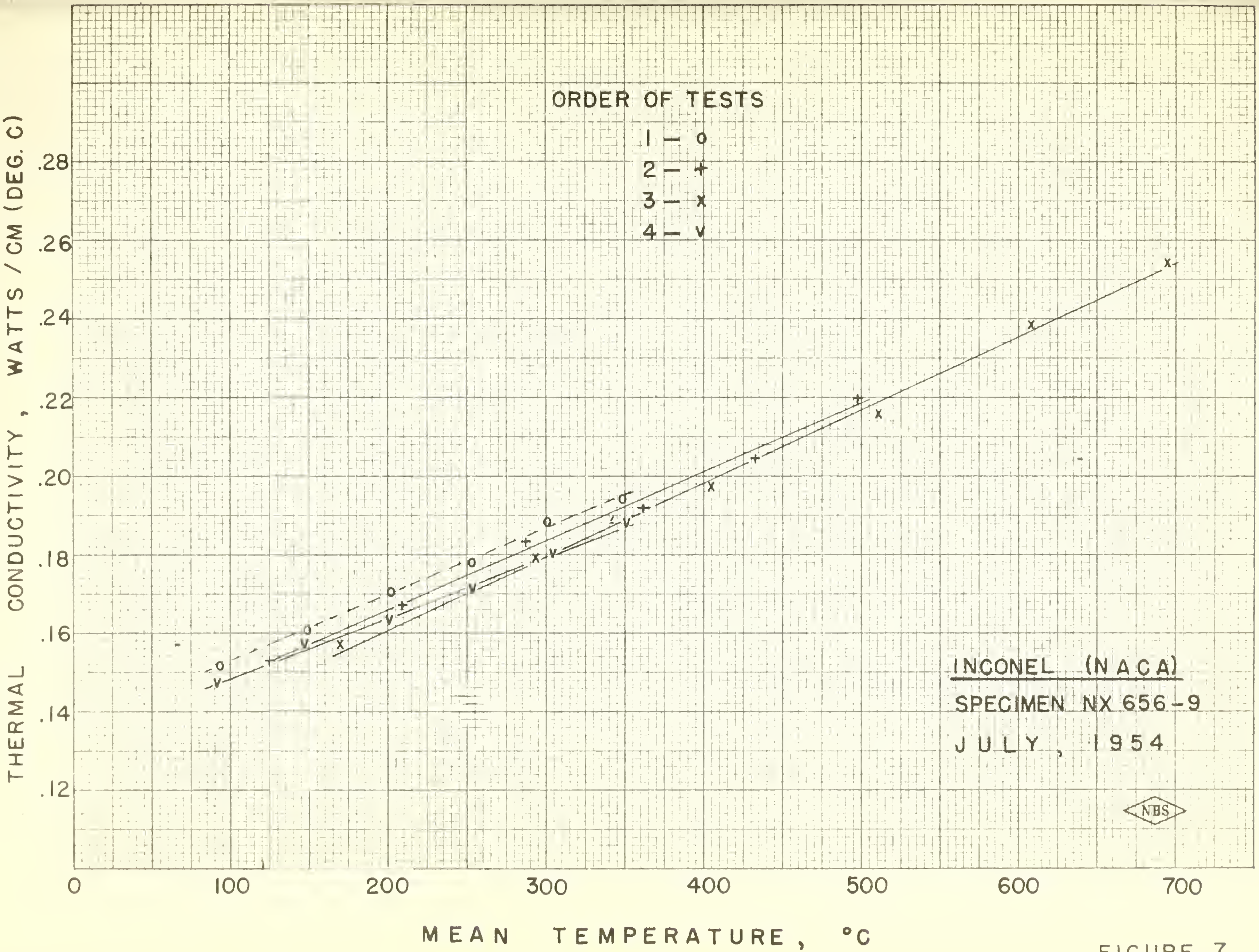

ORDER OF TESTS
1 — o
2 — +
3 — x
INCONEL (NACA)
SPECIMEN NX 656-8
REVERSED
JULY , 1954
THERMAL CONDUCTIVITY, WATTS / CM (DEG C)
.28
.26
.24
.22
.20
.18
.16
.14
.12
0
100
200
300
400
500
600
700
MEAN TEMPERATURE, °C

FIGURE 6A



ORDER OF TESTS
1 — o
2 — +
3 — x
4 — v
.28
.26
.24
.22
.20
.18
.16
.14
.12
THERMAL CONDUCTIVITY, WATTS / CM (DEG. C)
0
100
200
300
400
500
600
700
MEAN TEMPERATURE, °C
INCONEL (NACA)
SPECIMEN NX 656-9
JULY, 1954
NBS

FIGURE 7

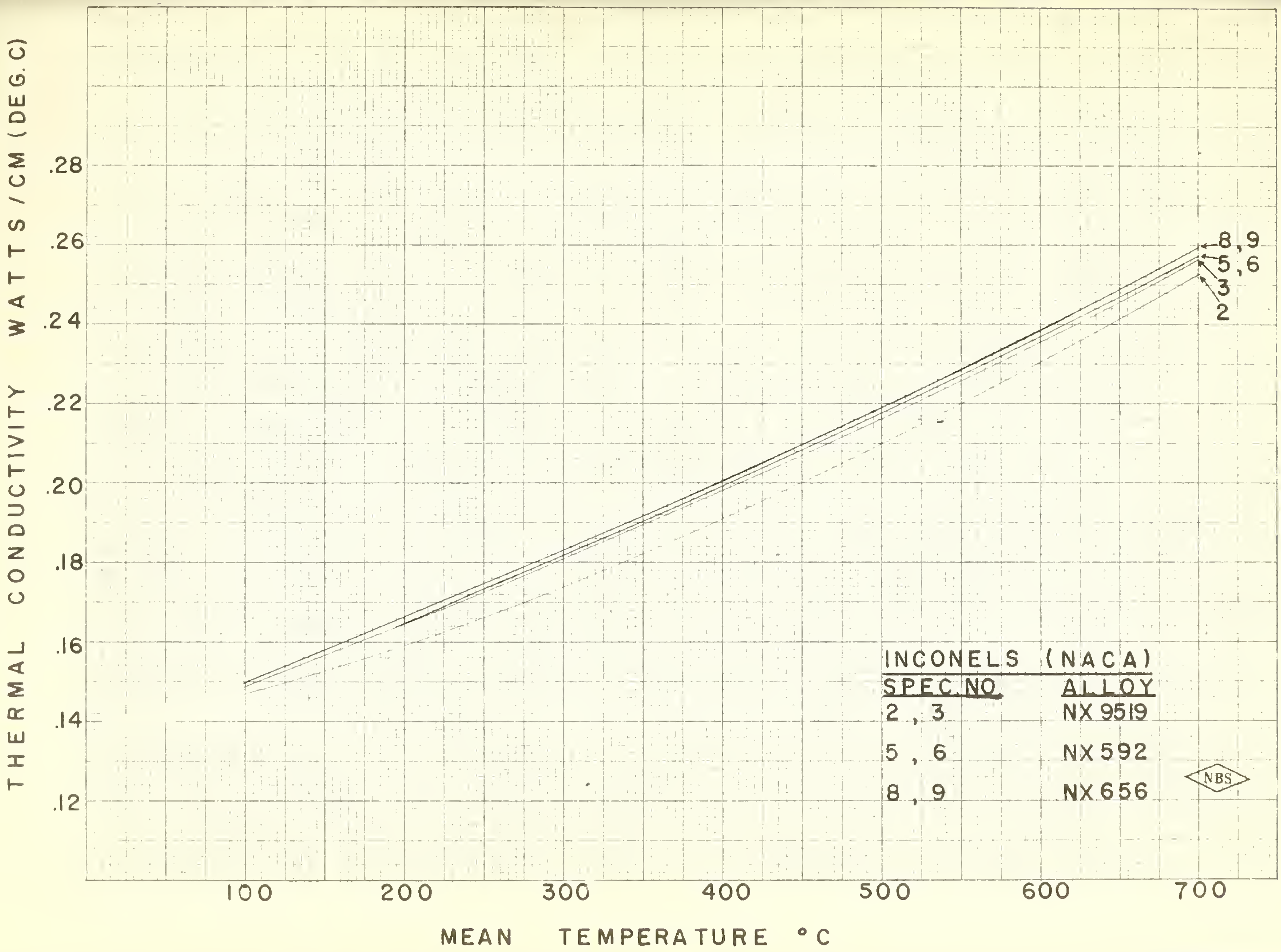

THERMAL CONDUCTIVITY WATTS / CM (DEG. C)
.28
.26
.24
.22
.20
.18
.16
.14
.12
100
200
300
400
500
600
700
MEAN TEMPERATURE °C
8, 9
5, 6
3
2
INCONELS (NACA)
SPEC. NO.
ALLOY
2, 3
NX 9519
5, 6
NX 592
8, 9
NX 656
NBS

FIGURE 8

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS